

TITLE OF THE INVENTION:

CVD CHAMBER CLEANING USING MIXED
PFCs FROM CAPTURE/RECYCLE

BACKGROUND OF THE INVENTION

5 [0001] The present invention is directed to recapture and/or recycle of perfluorocompounds (PFCs). In particular, the present invention is directed to recovery of PFCs used in semiconductor manufacturing processes for use in chemical vapor deposition (CVD) chamber cleaning.

10 [0002] PFC gas mixtures or compounds (e.g., C₂F₆ or CF₄) are used in semiconductor manufacturing processes as a convenient source of fluorine for the plasma etching of silicon-based materials (e.g., SiO₂, SiN_x, poly-Si). Due to strong infrared absorbances and long atmospheric lifetimes, however, PFCs are suspected of contributing to global warming. Responding to this concern, the global semiconductor industry has voluntarily agreed to minimize its PFC emissions. Reduction targets for the U.S., Europe and
15 Japan are 10% of 1995 levels by the year 2010. A strategy for achieving these emissions reductions is to capture the PFCs from the process effluent. For example, a membrane-based PFC recovery system has been demonstrated in M. Foder, R. Wimmer, J. Yang, and T. McCay, "Recovery of Perfluorocompounds (PFCs) from Semiconductor Manufacturing Processes Using a Membrane-Based System," *ECS Proceedings*, 99-8, 60 (1999).
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[0003] Additionally, typically, CVD chambers are cleaned using a C₂F₆/O₂-based RF plasma process as follows:



[0004] Here, PFC recovery is necessary because the influent C_2F_6 is not completely utilized, *i.e.*, the influent stream as well as the effluent stream contains C_2F_6 . Also, the plasma process generates some CF_4 . Since the PFC recovery system removes all of the acid gases (*e.g.*, SiF_4 , COF_2 and HF) and is designed to separate PFCs from atmospheric gases (*e.g.*, O_2 , N_2 , CO_2), the captured material is a mixture of both C_2F_6 and CF_4 . The generation of CF_4 during the CVD chamber clean process makes using the recovered PFC gas more difficult.

[0005] Attempts to reuse the recovered PFCs have focused on separating the mixture into its components (C_2F_6 and CF_4) followed by further purification. See, e.g., U.S.

Patent No. 5,502,969 (Jin et al.) directed to a cryogenic rectification system for fluorine compound recovery. Recovered C_2F_6 can then be used in existing C_2F_6 -based chamber clean processes. The goal is for the recovered components to meet the purity specifications of the virgin product. All impurities (including other PFCs) must only be present at trace levels. Typically, impurity levels required are less than 5 parts per million (ppm) except for N_2 which is around 250 ppm and O_2 which is around 100 ppm.

[0006] A process has also been developed whereby the PFC mixture is separated into its components via cryogenic distillation. The concentration of impurities in recovered C_2F_6 can indeed be reduced to the levels of virgin product. The shortcoming of this approach is economic. The cost of separating the PFC mixture and subsequent purification is higher than the cost of manufacturing the virgin C_2F_6 material. Additionally, distillation could be difficult if the recovered PFC's contain unsaturated fluorocarbons, such as CHF_3 , C_2HF_5 , etc. that may form azeotropes with C_2F_6 , resulting in the loss of valuable product. Furthermore, the presence of NF_3 having a close boiling point to CF_4 makes their separation by distillation practically impossible. At any rate, the recovered C_2F_6 and CF_4 gases will not be as pure as the virgin material and will cost more to produce.

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- [0007]** As taught in U.S. Application Serial No. 09/542,995, filed April 4, 2000, "Reclamation and Separation of Perfluorocarbons Using Condensation.", by W. T. McDermott, R. C. Ockovic, A. Schwarz, and R. Agrawal, cold trapping of PFC effluents, rather than membrane separation, may provide an economical feedstock for mixed PFC
- 5 chamber clean processes. Separation of PFCs by condensation may not completely recover C_2F_6 and CF_4 , *i.e.*, recovered effluent is not separated into single components with all impurities present at trace levels. This is, however, more economical than distillation and can be used as mixed PFC source gas for CVD chamber cleaning.
- [0008]** In Andrew D. Johnson et al., "Minimizing PFC Emissions from Existing PECVD
- 10 Tools: Optimization of the Chamber Clean Process of Record, *Semicon West 2000*, minimization of PFC emissions from cleaning PECVD chambers is described where the chamber clean process is optimized. Such optimization could occur by adjusting C_2F_6 flowrate, adjusting $O_2:C_2F_6$ ratio and/or adjusting pressure.
- [0009]** As indicated in M. A. Sobelewski, J. G. Langan, and B. S. Felker, "Electrical
- 15 Optimization of Plasma-Enhanced Chemical Vapor Deposition Chamber Cleaning Plasmas," *J. Vac. Sci. Technol.*, B16, 173 (1998), the use of C_2F_6 -based and CF_4 -based plasmas to clean CVD equipment is widespread. Typically, O_2 is added to either C_2F_6 or CF_4 to inhibit polymer deposition and enhance the etch rate. Mixed PFCs are not expected to provide for improvements in cleaning performance.
- 20 **[0010]** Finally, in Nakata, Kubota, Kaji, Yoda and Okumura, "Reduction of PFC Emissions by Gas Recirculation Cleaning in Plasma CVD," *IEEE*, 2001, a process is disclosed that is directed to a method for cleaning a CVD chamber using gas recirculation. Unused gas contained in the exhaust gas is returned to the chamber by a pump. No virgin C_2F_6 or CF_4 is added.
- 25 **[0011]** It is principally desired to provide viable reuse of PFCs recovered from semiconductor tool effluents.

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[0012] It is further desired to provide viable reuse of PFCs recovered from effluents that uses a mixed PFC source gas of C_2F_6 and CF_4 to clean, for example, CVD chambers.

[0013] It is still further desired to provide viable reuse of PFCs recovered from
5 semiconductor tool effluents where it is not necessary to separate and purify recovered PFC effluents.

BRIEF SUMMARY OF THE INVENTION

[0014] The present invention is directed to improving the performance of a CVD
10 chamber cleaning using recovered PFCs without subsequent purification. The relative concentrations of specific PFCs in the source gas can be chosen such that they are easily maintained by standard additions of specific virgin PFCs to the recovered mixed PFC product. Processes are chosen that do not result in a net increase in the amount of CF_4 and total gas volume. Specifically, higher C_2F_6 flow rates and O_2 concentrations
15 result in sustainable C_2F_6 -rich chamber clean processes. Other compounds present in the recovered stream, such as N_2 or O_2 , can also be maintained at a fixed level by standard additions to the product.

[0015] Here, the strategy for achieving these emissions reductions is to capture the PFCs from the process effluent. Once captured, however, these PFCs are reused. This
20 invention facilitates the recycling of the PFC gas mixture recovered from the effluent of semiconductor processing facilities.

[0016] The present invention is directed to a method of using PFCs recovered from the effluent of a CVD chamber cleaning process as an influent for the CVD chamber cleaning process. The method includes the steps of selecting a first PFC gas mixture
25 having a first ratio of C_2F_6 to CF_4 , and providing the first PFC gas mixture as the influent gas to the CVD chamber, wherein the influent gas reacts during the cleaning process to

create a CVD chamber effluent gas comprising a second PFC gas mixture having a second ratio of C_2F_6 to CF_4 . Virgin C_2F_6 or CF_4 is added to the CVD chamber effluent gas in sufficient quantity to create a third PFC gas mixture having the first ratio of C_2F_6 to CF_4 . The third PFC gas mixture is then used as the influent gas to the CVD chamber.

- 5 Virgin C_2F_6 or CF_4 continues to be added to the CVD chamber effluent gas to create the third PFC mixture and the third PFC gas mixture continues to be used as the influent gas to the CVD chamber.

[0017] O_2 may be provided to the third PFC gas mixture for use as influent gas to the CVD chamber.

- 10 **[0018]** The third ratio of C_2F_6 to CF_4 may be less than or equal to the following equation:

$$\frac{(1 - C + (C \cdot U))}{G \cdot C}$$

- 15 **[0019]** where U = Utilization of CF_4 in the plasma; G = Generation

[0020] frequency of CF_4 from C_2F_6 ; and C = Capture efficiency of CF_4 .

[0021] The third ratio of C_2F_6 to CF_4 may be less than or equal to about 0.32.

[0022] The third ratio of C_2F_6 to CF_4 is preferably greater than or equal to 1.

- [0023]** The third ratio of C_2F_6 to CF_4 is preferably adjusted by increasing the O_2
20 concentration and/or by using higher C_2F_6 flowrates.

[0024] The amount CF_4 in the effluent is preferably less than or equal to the amount of CF_4 in the influent.

[0025] The total gas volume of the effluent is preferably less than or equal to the total gas volume of the influent.

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BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0026] FIG. 1 is a graphical depiction of a concentration of PFCs in the effluent from a C_2F_6 -based CVD chamber clean.

[0027] FIG. 2 is a graphical depiction of volume of the ratio of C_2F_6 to CF_4 as a function of generation frequency of CF_4 from C_2F_6 and capture efficiency of CF_4 with respect to a preferred embodiment of the present invention.

[0028] Fig. 3 is a graphical depiction of generation frequency of CF_4 from C_2F_6 as a function of C_2F_6 flowrate and the ratio of O_2 to C_2F_6 with respect to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The present invention is directed to cleaning CVD chambers using mixed PFC source gases. The composition of the CVD chamber clean feed stocks can be altered so that the recovered product can be reused simply by addition of virgin PFCs. C_2F_6 , CF_4 , and any other needed gases (*e.g.*, O_2) can be added to the recovered material so that the product has a fixed composition. Chamber clean processes can then be developed which use this mixture, simplifying the reuse strategy.

[0030] The main difficulty in using the recovered PFC material is the generation of CF_4 during the chamber clean process. The concentration of PFCs in the effluent of a semiconductor process tool is shown in Fig. 1 during a typical C_2F_6 -based chamber clean process.

[0031] The gas usage, emissions and calculated utilization of C_2F_6 and generation of CF_4 are summarized below in Table 1.

	Influent	C ₂ F ₆ Utilization	CF ₄ Generation	Effluent
C ₂ F ₆	500 scc	44 %		280 scc
CF ₄	0 scc		31.6%	158 scc

Table 1

[0032] As described earlier, to reuse this captured effluent in current C₂F₆-based CVD chamber clean processes, the 158 scc (standard cubic centimeters) of CF₄, as indicated

5 in the example of Table 1, must be removed. However, since CF₄ -based plasmas are also used for CVD chamber cleaning, it is not necessary to separate the PFC mixture into its components, *i.e.*, the recovered PFC mixture can be used directly as a source gas for CVD chamber clean processes. If the CF₄ and other compounds made in the chamber clean process are included in the influent gas, the recovered product can be
10 reused by simple addition of those compounds that have higher utilization efficiencies.

Using the C₂F₆ utilization and CF₄ generation efficiencies from Table 1, an example chamber clean process using mixed PFC source gas is summarized in Table 2. For this example, the total PFC flow rate is still 500 sccm (standard cubic centimeters per minute) and a typical CF₄ utilization (5 %) is used.

	Influent	Utilization	CF ₄ Generation	Effluent
C ₂ F ₆	250 scc	44 %		140 scc
CF ₄	250 scc	5 %	32 %	318 scc

Table 2

[0033] To achieve the same ratio of gases as for the starting material, 178 scc of C₂F₆ is added to the recovered product. That is, by adding 178 scc of C₂F₆ to the 140 scc effluent, there are 318 scc of C₂F₆ and 318 scc of CF₄. Note that this assumes the

capture efficiencies of C_2F_6 and CF_4 are both 100 %. Although the total volume of the reconstituted gas, 636 scc (*i.e.*, 140 scc C_2F_6 + 178 scc C_2F_6 + 318 scc CF_4), is greater than the influent gas (500 scc), its composition is the same and can be reused in the mixed C_2F_6/CF_4 -based process.

5 [0034] The example summarized in Table 2 illustrates the problem associated with the formation of CF_4 during the clean process. If equal amounts of C_2F_6 and CF_4 are used as a source gas, the low utilization of CF_4 (5 %) results in the CF_4 emission (318 scc) being larger than the influent (250 scc), *i.e.*, more CF_4 is generated from C_2F_6 than is utilized in the plasma. Consequently, virgin C_2F_6 must be added to the recovered PFC mixture, which increases the total gas volume 27 %. More PFC gas is generated than
10 can be reused in the semiconductor process. The excess must again be stored indefinitely or be destroyed/abated if emissions reductions are to be meaningful.

[0035] The solution to this problem is to adjust the influent ratio of C_2F_6 and CF_4 so that there is a net decrease in CF_4 (*i.e.*, the volume of CF_4 generated must be less than the
15 volume of CF_4 recovered). Since no C_2F_6 is generated in the plasma, the volume of C_2F_6 effluent will always be less than its influent. From this condition, the limiting composition for the influent PFC gas mixture can be calculated:

$$\frac{C_2F_6}{CF_4} \leq \frac{(1 - C + (C \cdot U))}{G \cdot C}; \quad \text{Equation 1.}$$

20 [0036] where:

U= Utilization of CF_4 in the plasma;

G= Generation frequency of CF_4 from C_2F_6 ; and

C = Capture efficiency of CF_4

[0037] An example mixed PFC process ($C_2F_6/CF_4 = 0.32$) that satisfies the condition
25 (Equation 1) is summarized in Table 3.

	Influent	Utilization	CF_4 Generation	Capture Efficiency	Recovered

C ₂ F ₆	120 scc	44 %		95%	64 scc
CF ₄	380 scc	5 %	32 %	95%	379 scc

Table 3

[0038] Since the volume of recovered CF₄ is less than its influent, the total gas volume (500 scc) does not increase when the influent composition (C₂F₆/CF₄=0.32) is reconstituted by addition of virgin C₂F₆ (56 scc).

[0039] The process summarized in Table 3 is not, however, desirable for chamber cleaning because it is a CF₄-rich plasma. Since most CVD chamber clean processes are C₂F₆-based chemistries, a process where C₂F₆/CF₄ is greater than one is more acceptable. The sustainable PFC composition (Equation 1) is quite sensitive to the capture efficiency (C) and CF₄ generation frequency (G) as shown in Fig. 2.

[0040] Sustainable C₂F₆-rich chamber clean processes are achievable by reducing the CF₄ generation frequency (G) or CF₄ capture efficiency (C). Concerns over global warming have motivated the semiconductor industry to optimize their C₂F₆-based chamber clean processes. See, e.g. A. D. Johnson, W. R. Entley, and P. J. Maroulis, "Reducing PFC Gas Emissions from CVD Chamber Cleaning," *Solid State Technology*, p. 103, December 2000. Optimization involves adjusting the process parameters so as to reduce PFC emissions without increasing the time needed to clean the CVD chamber. Optimized chamber clean processes generally have a lower C₂F₆ flow rate, lower O₂ concentration, and higher pressure. Unfortunately, this strategy increases the amount of C₂F₆ converted to CF₄. See FIG. 3. An alternative strategy is possible if the PFC effluents are captured for reuse. By increasing the O₂ concentration and using higher C₂F₆ flow rates (Fig. 3), the CF₄ generation can be reduced substantially (Fig. 3). Although these processes have higher C₂F₆ flow rates, this is unimportant if the effluent is captured and reused.

[0041] Table 4 provides an example C₂F₆-rich chamber clean process whereby the recovered effluent can be reused without generating excess mixed PFC product. Higher flow rates are expected to result in a lower C₂F₆ utilization. Since the process effluent is recovered, this should be a minor contributor to PFC emissions (which depends upon the C₂F₆ capture efficiency). Lower C₂F₆ utilizations provide the benefit of reducing the amount of virgin C₂F₆ necessary to restore initial PFC composition.

	Influent	Utilization	CF ₄ Generation	Capture Efficiency	Recovered
C ₂ F ₆	1000scc	20 %		90%	720 scc
CF ₄	1000scc	5 %	15 %	90%	990 scc

Table 4

[0042] Although illustrated and described herein with reference to specific embodiments, the present invention nevertheless is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims without departing from the spirit of the invention.